Tape as a means to ensure air- and watertightness of building joints – experimental assessment

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Abstract. *Building façades have evolved from traditional mass buffering systems towards face-sealed systems in the 60's and 70's. Due to numerous problems with water ingress, façade systems have then evolved towards more reliable – and more expensive – drained systems that have a higher degree of redundancy. Now the building industry is facing new challenges in the renovation sector. There is a need for easy and rapid renovation concepts, and often tapes are used in these systems to ensure the airtightness and/or watertightness. In this paper a range of different tapes were tested in lab conditions. Tapes and silicone strips were installed on three different substrates, to test the airtightness (EN 12114) and watertightness (EN 1027). The test sequence comprised subsequent steps in which the airtightness was measured before and after the watertightness test. Subsequently, the samples were subjected to 200 pulsations of 1000Pa mimicking severe wind gusts to induce artificial ageing. Afterwards parts of the tapes were covered with a polymer emulsion which is applied with a paintbrush and dries to a permanent flexible airtight membrane, to locate leakage paths. For airtightness, the impact of the contact angle and therefore the substrate was found to be most important. Test results showed that the watertightness of taped joints is rather poor. More specifically at the crossing of tapes water ingress was often recorded at lower pressure differences. The artificial ageing did not have a significant impact on the airtightness or watertightness.*

Introduction

In 2014 the residential sector was responsible for 19% of the energy use in Flanders. Only the industrial sector used more, i.e. 22% [1]. A lot of this energy is used by post-war housing blocks that have never been energetically renovated. Therefore, there is a need for rapid and cost-efficient renovation concepts. The use of prefabricated façade panels can offer a solution. Due to the high level of prefabrication of these panels, the construction time on site is reduced considerably. Also the financial cost will be significantly reduced since these panels can be fabricated by standardized processes in large quantities. Several research-projects concerning the use of prefabricated façade panels for energetically renovating housing blocks have already been conducted. Two examples are '*Annex 50: Prefabricated Systems for Low Energy Renovation of Residential Building*' [2] and '*TES Energy Façade: prefabricated timber based building system for improving the energy efficiency of the building envelope*' [3]. Both give a good overview of prefabricated systems that can be used. However, methods to ensure the airtightness and watertightness of the joints between the prefabricated façade panels are not discussed in detail.

As a good overall airtightness and watertightness are considered important factors to obtain energy-efficient buildings, a lot of research has already been done on these topics. However, only a few focus on the air and water leakage through joints between different building components and the durability of the sealing materials. In a study performed by Relander [4], different solutions to seal the window-wall interface were investigated. The airtightness of different materials, i.e. mineral wool, self-expanding sealing strips, backer rod, tape and vapour and wind barriers, was measured as well as the influence of an incorrect mounting of the materials. One of the conclusions was that tapes are the most airtight but therefore also the most vulnerable to faulty workmanship. Furthermore, a large difference in airtightness between the tapes and the self-expanding strips, which were the least airtight, was found (10,87 m^3/h.m).

Apart from faulty workmanship, also the impact of the durability of the tapes on the airtightness of the joints can be investigated. Currently, only very little is known about the durability of tapes and glues and no normative test procedures exist. In Germany, a new standard DIN 4108-11 is being developed to define minimum requirements for ensuring durability of adhesive joints using adhesive masses and adhesive tapes to create an airtight building envelope.

Langmans [5] performed a study on the air permeability and durability of two different types of tape, perfectly adhered to a wood fibre cement board substrate. The test samples consisted of two boards, connected by two spacers creating a joint of 2 mm. Three artificial ageing methods were applied: thermal loads, hygrothermal loads and combined UV and vapour loads. The results showed that the air permeability of the taped joints was very low ($1{,}55.10^{-4}$ m^3/h.m for tape A and $1{,}95.10^{-5}$ m^3/h.m for tape B at a pressure difference of 50 Pa). Only a small increase of the air permeability was measured for both tapes after the thermal and hygrothermal loads (+0.001 m^3/h.m at a pressure difference of 50 Pa). For tape A, a slightly higher impact was observed after the UV and vapour cycles (+0.002-0.003 m^3/h.m at a pressure difference of 50 Pa). However, it is stated that the impact on the overall airtightness of a building is still very small. For a building with a volume of 1083 m^3 and 1280 m of joints in the exterior layer, an increase of the air permeability of 0.003 m^3/h.m results in an increase of the n_{50}-value of only 0,003 1/h (Passive house standard is 0,6 1/h).

At the Lawrence Berkeley National Laboratory (LBNL) [6,7] durability tests were performed to evaluate six types of sealants on duct connections, as well as baking tests to evaluate sealants on sample substrates representative of the materials used in duct systems. During the durability test, the samples were exposed to high pressure and a small temperature difference between the outside and inside of the specimen. Periodically the samples were removed from the test machine, cooled down to room temperature and the air flow was measured at a pressure of 25 Pa. During the baking test, the samples were heated at 100°C during 60 days, according to UL 1818B-FX, and a visual inspection was performed once a week. The test results showed that failure of the sealants mostly occurred at high temperatures. Typical minor deteriorations observed, were discoloration, wrinkling and oozing. The major deteriorations observed, were shrinking, peeling, delamination and cracking.

Furthermore, both Ackermann [8] and Gross & Maas [9] studied the peel force of several tapes and glues. Ackermann [10] performed standard 180° peel tests for eight different tapes on seven different surfaces as well as artificial ageing tests for both static and dynamic stress to study the long-term performance of adhesive tapes. The static test was conducted by means of tape adhered to a substrate at one end and a load of 0,5 kg was attached at the other end of the tape while being placed in a climate chamber at 23°C and 50% RH. To simulate the influence of gusts, the loads were situated on a plate which at one point dropped down and the loads therefore influenced the adhesives with a jerk, simulating gusts. The dynamic test was performed with the same boundary conditions but the load was applied cyclically. The peel test was performed on tapes conditioned by several hygrothermal cycles. Analysis of the test results showed that no correlation could easily be made between the different ageing techniques and the different sample products. Also the influence of the length of the tests was very ambiguous. For example: sometimes the results showed that there was an increase in peel strength after ageing for one substrate and a decrease for another. But when the ageing period was doubled, the opposite effect was observed.

It can be stated that only a limited amount of literature on the air- and watertightness of sealed joints and tapes is available. The performed research mostly addresses the peel force of the tape and the

influence of artificial ageing by means of changing temperature and relative humidity. The impact of the artificial ageing on the air leakage of the taped joints is only investigated by Langmans.
The aim of this investigation is to measure and compare the performance of different tapes and a silicone strip to ensure air- and watertightness of joints, as well as the influence of the substrate, the impact of wind gusts by means of a mechanical ageing and the influence of crossings between horizontal and vertical joints on the overall leakage.

Classification systems and standards

To the knowledge of the authors, no test standards, classification systems or performance requirements exist specifically for the airtightness and watertightness of joints or tapes in the European framework for standards and codes. ift Rosenheim however (Institut für Fenster und Fassaden, Türen und Tore, Glas und Baustoffe), a German testing institute for evaluation of construction products, performs testing of windows, facades, building materials and glass including the air- and watertightness of the window-wall interface and artificial ageing. As a result, they developed an application guideline for windows and doors, i.e. ift richtlinie FE 05/2 Directive for the Evaluation of the Minimum Classifications dependent on the Load, Part 1: Resistance to Wind Load, Watertightness, Air Permeability [11]. The American Standard ASTM E2357 [12] describes a test method to determine the air leakage of complete air barrier assemblies, including sealed penetrations and joints in the wall assembly.

A Dutch standard NEN 2687 [13] specifies 3 airtightness classes: class 1 (basic), class 2 (good), class 3 (very good). SBR, a Dutch research foundation [14], has published guidelines for maximum air leakage rates of different building components and interfaces to comply with the maximum overall leakage of the building. The maximum air leakage for joints between roof panels and between facade and structural wall for airtightness class, 1, 2 and 3 are respectively 0,01; 0,005 and 0,001 $dm^3/(s.m.\Delta P^n)$. With $n = 0{,}625$ as a mean value, the air leakage at a pressure difference of 50 Pa for each class becomes: 0,415; 0,208; 0,042 $m^3/h.m$. The Belgian Building Research Institute (WTCB) [15] does not prescribe a specific maximum air leakage for joints. However, a maximum air flow of 0,1 $m^3/h.m^2$ at a pressure difference of 50 Pa is given as a guideline for a material to perform as an air barrier. The American Acceptance Criteria AC38 published by ICC-ES [16] prescribe an air permeance less than or equal to 0,02 $dm^3/s.m^2$ at a pressure difference of 75 Pa for a material to be evaluated as an air barrier material. This results in a maximum air leakage of 0,0559 $m^3/h.m^2$ at a pressure difference of 50 Pa and with $n = 0{,}625$. This is half of the maximum air leakage that is prescribed by the WTCB.

Van Den Bossche [17] compared the performance requirements for the watertightness of window frames in different countries. Besides some similarities such as a minimum (and for most codes also a maximum) performance level irrespective of the wind loads and an increase in the required performance level as a function of wind load, also major discrepancies between the different codes were found. To evaluate the watertightness of the tested materials the Belgian standard NBN B 25-002-01 [18] is used. This standard provides a classification according to the height of the building and the location, e.g. a window at a height of 25-50 m, in an open terrain or near the coast has to meet the requirements of class 9A, which corresponds to no water leakages at a pressure difference of 600 Pa.

Test setup and methodology

The airtightness and watertightness of three different tapes and one silicone strip adhered to three different substrate materials is measured before and after mechanical ageing and wetting. Furthermore, the influence of the different substrate materials is investigated as well as the effect of crossing joints. The following sections describe the test setup, the applied materials and test procedure.

Test setup. Laboratory measurements were performed by means of three test setups in order to investigate the airtightness and watertightness of the different tapes and silicone strips on three different substrate materials. The three test setups are all built in the same way and consist of 16 panels with a size of 29,5 x 29,5 cm which are screwed onto a wooden structure surrounded by a

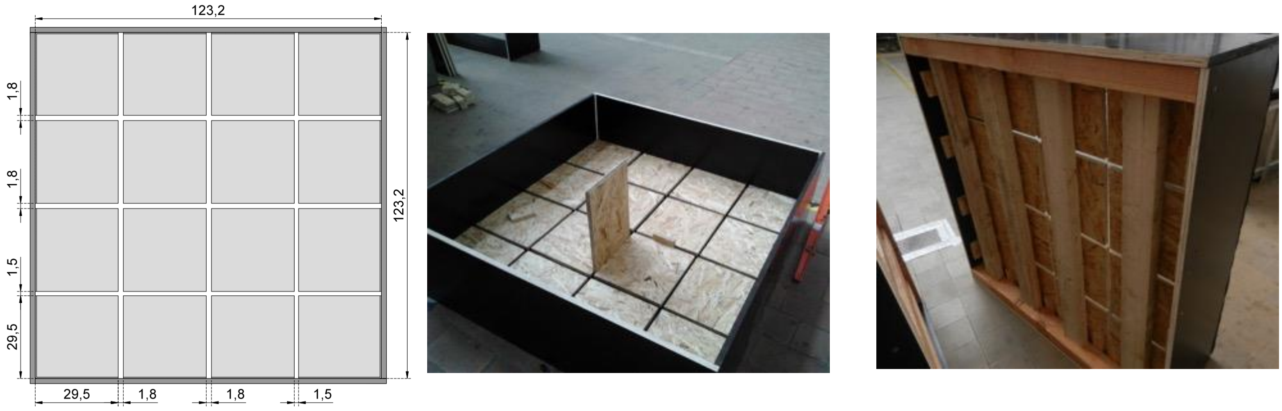

Fig. 1: Test setups: left: dimensions of the setups in cm; middle: 16 panels screwed onto structure; right: wooden structure surrounded by framework at the back of the test setup

framework of plywood. The inner size of the framework is 1,232 x 1,232 m. The perimeter joints between the framework and the panels are made airtight by means of caulking. Between the 16 panels, 3 vertical joints and 3 horizontal joints are created. Two vertical joints have a width of 18 mm. The other vertical joint has a width of 15 mm. The same principle is applied for the horizontal joints.

Materials. The tests are performed for three different tapes: Tape A, Tape B and Tape C and one type of silicone strip. Table 1 summarizes the material characteristics.

Table 1: Summary of material characteristics

	Width	Composition	Adhesive	Processing temperature
Tape A	60 mm	LDPE-film with diagonal reinforcement	unknown	+5°C to +40°C
Tape B	100 mm	combination of PET-film and PA-foil, variable vapour diffusion resistance	acrylate	+5°C to +30°C
Tape C	60 mm	PP film	SOLID-glue	from -10°C
Silicone Strip	300 - 50 mm	preformed silicone elastomer extrusion	one-part, neutral curing, low modulus silicone sealant	-25°C to +50°C

All materials are designed for both interior and exterior applications. Three substrate materials are used, i.e. OSB 3 with a thickness of 18 mm, bituminous impregnated fibreboard with an additional bituminous coating on one side (to improve the airtightness) and a thickness of 18 mm and concrete tiles with a thickness of 30 mm.

Test procedure. The airtightness of the sealing materials is measured in a standard calibrated test rig according to EN 12114 [19]. The airflow is measured at eight fixed pressure differences 50 - 100 - 150 - 200 - 250 - 300 - 450 - 600 Pa. The airflow is derived by measuring the pressure difference over a calibrated opening in the used diaphragm. The results are curve fitted using the power law to obtain the leakage for each pressure difference and the leakage coefficients, C and n:

$$V = C.\Delta P^{n}. \qquad (1)$$

V is the airflow through the setup [m^3/h] and ΔP stands for the pressure difference over the test setup [Pa]. C [$m^3/(h.Pa^n)$] is the leakage coefficient and n [-] is the leakage exponent, obtained from the curve fitting. To make a comparison between the performance of the different tapes and silicone strip, the air leakage at a pressure difference of 50 Pa is calculated for each material. For each measurement an error calculation is performed. The error propagation in the power law can be determined by eq. 2 [20]:

$$\sigma_V^2 = \sigma_C.\sigma_n[(\Delta P^n)^2.\frac{\sigma_C}{\sigma_n} + (C.\Delta P^n.\ln(\Delta P))^2.\frac{\sigma_C}{\sigma_n} + 2C.\Delta P^{2n}.\ln(\Delta P).r]. \tag{2}$$

The airflow through the sealed joints (V_{joints}) is derived by subtracting the air leakage through the substrate ($V_{substrate}$), the frame surrounding the test panels (V_{frame}) and the air leakage through the test rig ($V_{test\ rig}$), from the total measured air flow (V_{total}):

$$V_{joints} = V_{total} - (V_{substrate} + V_{frame} + V_{test\ rig}). \tag{3}$$

The total air leakage through the substrate, the frame and the test rig is measured by covering the joints between the panels of the test setup with a liquid fibre reinforced polymer emulsion which is applied with a paintbrush and dries to a permanent flexible airtight membrane (the airtightness of this coating is tested by means of a smaller test setup with an OSB substrate):

$$V_{joints\ covered} = V_{substrate-parts\ coverd} + V_{frame} + V_{test\ rig}. \tag{4}$$

$$V_{substrate} + V_{frame} + V_{test\ rig} = V_{joints\ covered} + V_{substrate\ correction}. \tag{5}$$

Fig. 2: Calculation of air leakage sealed joints; left: different air leakages through test setup; middle: covered joints; right: covered part of substrate

It should be noted that by applying the coating on the joints, also a part of the substrate is covered to include the lateral air leakages (2 cm on each side of the tape). As the initially flowing air through the covered part of the substrate (red hatched part of fig. 2 right) is not part of the airflow through the joints, a correction needs to be made by means of $V_{substrate\ correction}$. These measurements are performed for each test setup. The error on the leakage through the tested sealing material will thus be a combination of two measurements. The total error is calculated by the adding in quadrature of the absolute errors of both measurements. Summarized, the total error is a combination of a relative error (3,965%) of the measuring equipment, the propagation error by curve fitting the 8 measurements, the extrapolation of the curve to one air leakage at 50 Pa and the effect of subtracting two airflows.

The watertightness of the sealing materials is measured in a standard calibrated test rig according to EN 1027 [21]. A spraying rack is installed in each test setup at a distance of 25 cm from the surface of the panels. Each test setup is submitted to a static watertightness test using a spray rate of 2 l/min/m^2. The first 15 minutes of water spraying, no pressure difference is created. After these first 15 minutes, the pressure is raised every 5 minutes from 50 - 100 - 150 - 200 - 250 - 300 - 450 - 600 - 750 - 900 - 1050 - 1200. Each visible water leak is documented with the related time and pressure difference. The watertightness test was ended when no more visible separation between the different leakages could be made.

A mechanical ageing of the tapes and silicone strip applied to the different substrates, is performed to investigate the impact of severe wind gusts. Hereby, the pressure difference is repeatedly increased and reduced and stabilized for only a short period. In total 200 pulsations of +/- 1000 Pa are applied according to EN 12211 [22].

The different tapes and silicone strip are submitted to a fixed test procedure. First, the initial airtightness of the materials is measured (1). For tape A and B also the initial watertightness is measured (2). Thereafter, a mechanical ageing is performed by means of 200 pulsations of 1000 Pa, to test the impact of wind gusts on the airtightness of the materials (4,5). Subsequently, the test setup is sprayed with water during a watertightness test (6). Thereafter, the airtightness of the setup in wet conditions is measured. After a drying period of 24 hours, the airtightness is measured again to determine the influence of the bonding of the adhesive of the sealing material on the substrate (7). Finally, each test setup is systematically covered with a liquid polymer emulsion which dries to an airtight coating in order to make a separation of the total air leakage and to investigate the impact of a coating on the watertightness.

$$\text{test 8:}\ V_{\text{crossings covered}} = V_{\text{intermediate joints}} + V_{\text{substrate}} + V_{\text{frame}} + V_{\text{test rig}} \tag{6}$$

$$\text{test 10:}\ V_{\text{joints covered}} = V_{\text{substrate}} + V_{\text{frame}} + V_{\text{test rig}} \tag{7}$$

$$\text{test 12:}\ V_{\text{surface covered}} = V_{\text{frame}} + V_{\text{test rig}} \tag{8}$$

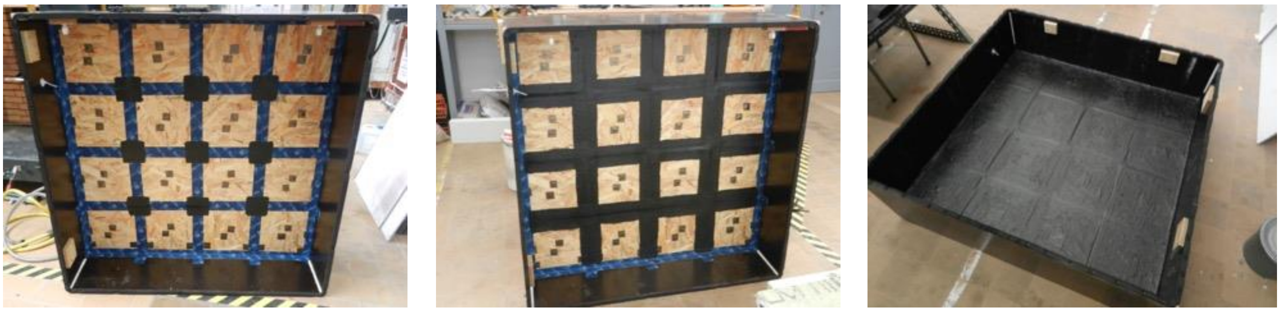

Fig. 3: Systematically covering if crossings, joints and complete surface

By subtracting the result of one test from the results of another test, $V_{\text{crossings}}$, V_{joints}, $V_{\text{substrate}}$, V_{frame} and $V_{\text{test rig}}$ could be calculated, e.g. $V_{\text{test 10}} - V_{\text{test 12}} = V_{\text{substrate}}$.

Table 2: Overview of test program

	OSB				**Fibreboard**			**Concrete**	
	Tape A	Tape B	Tape C	Silicone Strip	Tape A	Tape B	Tape C	Tape A	Tape B
1. Initial airtightness test	x	x	x	x	x	x	x	x	x
2. Initial watertightness test	x	x			x	x		x	
3. Airtightness test wet/24h drying	x	x				x		x	
4. Mechanical ageing	x	x	x	x		x	x	x	x
5. Airtightness test after ageing	x	x	x	x		x	x	x	x
6. Watertightness test after ageing	x	x	x	x		x	x	x	x
7. Airtightness test wet/24h drying	x	x	x	x		x	x	x	x
8. Airtightness test crossings covered	x	x	x	x		x	x	x	x
9. Watertightness test crossings covered		x	x	x		x	x	x	x
10. Airtightness test joints covered	x	x	x	x		x	x	x	x
11. Watertightness test joints covered	x	x	x	x		x	x	x	x
12. Airtightness test complete surface covered	x			x		x		x	

Test results and discussion

Airtightness. The air leakage through the different sealing materials (V_{joints}) is derived from the subtraction of the air leakage of test 10 (sealed joints covered with an airtight coating $V_{joints\ covered}$) from the total air leakage of test 7 (after a drying period of 24h V_{total}), and by means of eq. 3. This results in relatively large 95% confidence intervals (represented by the error bars in fig. 4). Figure 4 shows the final airflow per meter joint of the different tapes and silicone strip at a pressure difference of 50 Pa. The dashed line in figure 4 represents the requirement for a very good airtightness according to SBR (0,042 m^3/h.m) [14].

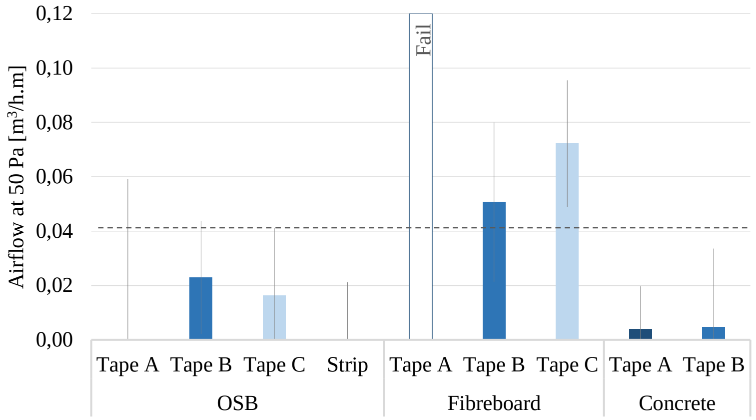

Fig. 4: Final airflow joints sealed with tapes and silicone at 50 Pa pressure difference

These measurements show that tapes adhered to a concrete substrate and silicone strips applied to OSB-panels were the most airtight. In contrast, the largest air flow rates were recorded for the tapes on bituminous impregnated fibreboards. Tape A and B were applied to fibreboards which were first treated with a primer to create a better bonding of the fibres and a hardened surface. Tape C was applied to fibreboards with an additional airtight layer. Even with the primer or the additional layer, the adhesion forces between the glue of the tape and the fibreboard and the adhesion forces between the fibres were low which even caused failure of tape A. A reduced bonding of tape A at the crossings was visible after wetting and a drying period of 24 hours. When pressure was applied, adhesive failure occurred at the crossings. For both the OSB substrate and concrete substrate the better adhesion of the tape resulted in lower airflows. Tape A (0,004 ± 0,016 m^3/h.m) and B (0,005 ± 0,029 m^3/h.m) applied to the concrete substrate both meet the requirement for a very good airtightness according to SBR (0,042 m^3/h.m dashed line in fig. 4). Also for the silicone strip adhered to the OSB substrate, low air flow rates were recorded. As the silicone layer could be pressed to fill the imperfections of the OSB surface, a low contact angle between the silicone molecules and the OSB could be obtained which resulted in a good bonding. For all of the sealed joints of the OSB substrate (tape A: -0.004 ± 0,063 m^3/h.m; tape B: 0,023 ± 0,021 m^3/h.m; tape C: 0,016 ± 0,025 m^3/h.m; silicone strip: -0,002 ± 0,023 m^3/h.m), the absolute measurements are below the maximum air leakage for a very good airtightness according to SBR.

Figure 5 shows the initial airflow of the test setups (1), the airflow after a drying period of 24 hours after wetting during a watertightness test (initially (3) or after mechanical ageing (7)) and the airflow after mechanical ageing (5). The airflow of the entire setups includes the airflow of the substrate (0,5-0,6 m^2/setup, depending on the width of the tape) and the airflow of the sealed joints (6 x 1,232 m). Tape A was applied to OSB panels with a measured air leakage of 1,15 ± 0,31 m^3/h.m^2 at a pressure difference of 50 Pa. It is clear that this airflow is much larger than the maximum air leakage provided as a guideline by WTCB (0,1 m^3/h.m^2). It should be noted that the airflow of the OSB was measured after wetting and a drying period of 24 hours at 50 Pa pressure difference, which results in an increase of the air leakage due to swelling of the OSB fibres. However, the increase in air leakage is not large enough for the initial air leakage to fulfil the requirement of WTCB. Tape B, C and the silicone strip were applied to another brand of OSB with a recorded airflow of 0,28 ± 0,07 m^3/h.m^2 at a pressure difference of 50 Pa. On the one hand this value is less than half of the air leakage of the previous OSB but on the other hand the recorded air leakage is still larger than the maximum air leakage of WTCB. Therefore, it can be stated that OSB is not always a reliable air barrier material. Tape B was applied to the bituminous impregnated fibreboard treated with a primer and an additional bituminous coating is situated on the backside of the panel. An airflow of 0,73 ± 0,19 $m^3/h.m^2$ at 50 Pa was recorded. In contrast, tape C was applied to the additional bituminous coating of the fibreboard and an airflow of 0,075 ± 0,187 $m^3/h.m^2$ at 50 Pa was measured, which is ten times smaller than the airflow of the previous setup. If the tape is applied to the additional bituminous coating, a continuous air barrier layer is created. In contrast, when the tape is applied to the other side, the air can flow through the substrate and a larger air leakage is recorded. For the concrete panels, no airflow was recorded.

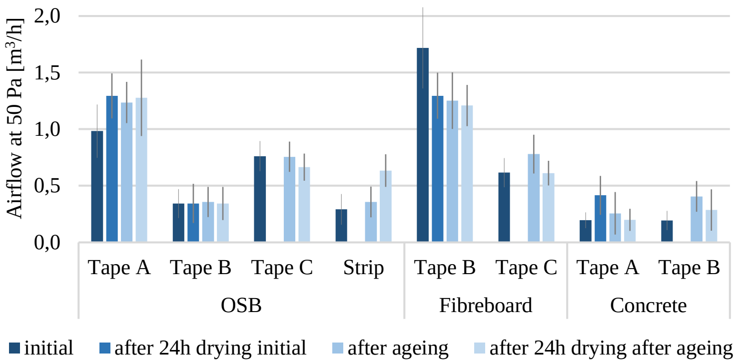

Fig. 5: Airflow of test setups at 50 Pa initially, after wetting/drying and after ageing

For tape A, an increase of the airflow was recorded after the first time of wetting and a drying period of 24 hours, as a result of a reduced adhesion of the tape on the substrate. For tape B and C, the opposite effect occurs, in particular on the fibreboard substrate. The increased airflow of the test setup with silicone strip is mainly due to the swelling of the OSB fibres. After mechanical ageing no remarkable difference of the air leakage was measured if this ageing was preceded by wetting and drying. When the mechanical ageing was performed right after the initial airtightness test, only a small significant increase of the air leakage through tape C on the fibreboard substrate and tape B on the concrete substrate was measured. The second time of wetting and a drying period of 24 hours has no impact on the air leakage of the setups.

Furthermore, the impact of 9 crossings on the overall air leakage in comparison with the impact of the intermediate parts of the joints (4,9 – 5,2 m depending on the width of tape) is tested by covering the crossings and afterwards the sealed joints with an airtight coating. Next to that, 2 cm of the substrate on each side of the tape was covered to include lateral air leakages. Figure 6 shows the air flow per crossing and per m joint at 50 Pa pressure difference. The error bars in figure 6 represent the 66% confidence interval.

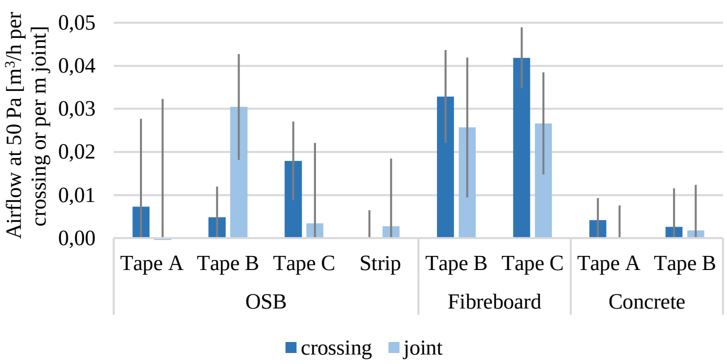

Fig. 6: Airflow of crossings and intermediate joints at 50 Pa

For tape B applied on OSB, the impact of the joints on the total air leakage is larger than the impact of the crossings. For tape B applied on the fibreboard substrate this difference was not observed. In contrast, for tape C the impact of the crossings is larger for both the OSB and fibreboard substrate. However, due to the relatively large absolute errors of the measurements, no conclusive observations could be made.
Since the different panels are not situated perfectly in the same plane, the tape needs to bridge small differences in height. This results in a reduced adhesion between the tape and the substrate mainly at the crossings. At these crossings a vertical tape needs to overlap a horizontal one which results in an additional difference in height and a reduced adhesion. Due to the thickness of the silicone strip, the adhesion between the strip and the silicone was insufficient at some locations of the crossings. Therefore, the addition of silicone at the 9 crossings resulted in a large decrease of the air flow (initially: 1,50 ± 0,17 m^3/h - after addition of silicone: 0,29 ± 0,15 m^3/h). Also the application of additional crosses of tape diagonally adhered over the crossings of tape C to the bituminous impregnated fibreboard reduced the air leakage with more than 50% (initially: 0,58 ± 0,10 m^3/h – after addition of cross: 0,24 ± 0,12 m^3/h).

Fig. 7: Impact of crossings; left: openings at crossings silicone strip; middle: addition of silicone at crossings; right: addition of crosses of tape at crossings

Both tapes and silicone strip are pressure-sensitive adhesives, which means they need pressure to ensure bonding. Therefore, attention must be paid to pressurize the tape and silicon strip sufficiently especially at the crossings where an overlap of a vertical and horizontal tape exists to ensure a good adhesion.

Table 3: Summary of results airtightness (air flow at 50 Pa)

		initial [m^3/h]	initial wetting/drying [m^3/h]	After mechanical ageing [m^3/h]	Wetting/drying after mechanical ageing [m^3/h]	Airtightness of sealed joints [m^3/h.m]
OSB	**Tape A**	0,98 ± 0,24	1,29 ± 0,20	1,24 ± 0,18	1,28 ± 0,34	-0,004 ± 0,063
	Tape B	0,34 ± 0,13	0,34 ± 0,17	0,36 ± 0,13	0,34 ± 0,15	0,023 ± 0,021
	Tape C	0,76 ± 0,13		0,76 ± 0,13	0,66 ± 0,12	0,016 ± 0,025
	Strip	0,29 ± 0,14		0,36 ± 0,14	0,63 ± 0,14	-0,002 ± 0,023
Fibreboard	**Tape A**	1,34 ± 0,25	Fail			
	Tape B	1,72 ± 0,36	1,30 ± 0,20	1,25 ± 0,25	1,21 ± 0,18	0,051 ± 0,029
	Tape C	0,62 ± 0,13		0,78 ± 0,17	0,61 ± 0,11	0,072 ± 0,023
Concrete	**Tape A**	0,20 ± 0,07	0,42 ± 0,17	0,26 ± 0,19	0,20 ± 0,10	0,004 ± 0,016
	Tape B	0,19 ± 0,09		0,41 ± 0,14	0,29 ± 0,18	0,005 ± 0,029

Watertightness. Figure 8 shows at what pressure difference the first water leak was observed for each setup. The dashed line represents the requirements of class 9A (height of 25-50 m and near the see or open terrain) according to the classification of NBN B 25-002-01 for windows [18].

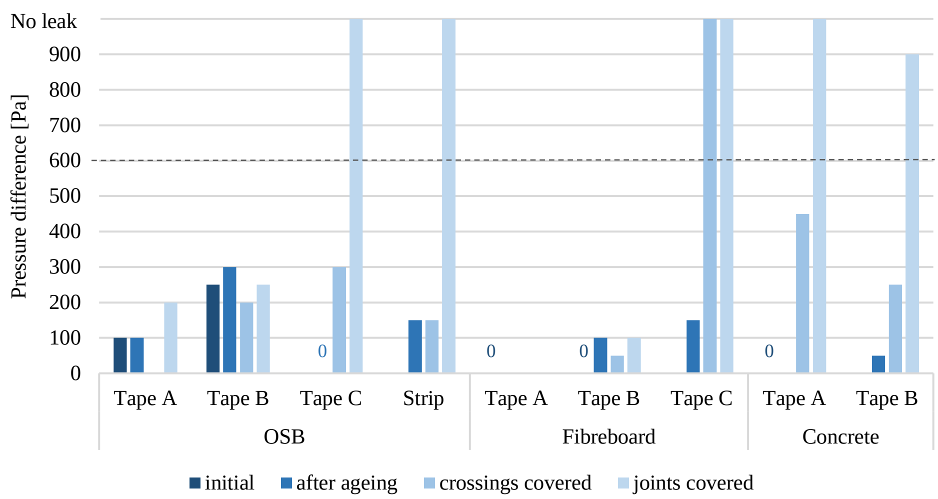

Fig. 8: Pressure difference first observed water leaks

In the test sequence, the horizontal joint is always sealed first and thereafter the vertical joint. The results show that the watertightness of the tapes and silicone strips is rather poor. Even at small pressure differences or without a pressure difference leakages were observed, mainly at the crossings. The watertightness of the tapes and silicone strip is initially not sufficient to meet the requirements of a class 9A according to NBN B 25-002-01 for windows [18] which corresponds to no water leakages at a pressure difference of 600 Pa (represented by the dashed line in fig. 8). However, in reality an airtight layer on the inside of the building envelope will reduce the pressure difference (partially) over the watertight layer. In addition, water is sprayed directly onto the sealed joints. In reality, a cladding is usually installed in front of these joints. The watertightness test is therefore a worst-case scenario. As a result, these requirements are perhaps too severe to compare with the obtained results. When the watertight layer has an airtightness similar to the airtightness layer, half of the wind load will act on the watertightness layer. If the air barrier is 10 times more airtight than the watertight layer, a pressure equalization above 90% is typically obtained [23]. Assuming a conservative and safe approach, one might adopt 300 Pa as a reasonable generic performance requirement if no further information is available.

The first time of wetting and drying has an impact on the performance of the tested materials. The bonding of the adhesive of tape B on the substrates for example improves after wetting and drying and therefore results in an increased watertightness. The first leaks occur at the same location but at a higher pressure difference: first leak OSB initial: 250 Pa – first leak OSB second time of wetting: 300 Pa; first leak fibreboard initial: 0 Pa, first minute of test – first leak fibreboard second time of wetting: 100 Pa. Furthermore, the subsequent times of wetting and drying also have an impact on the performance of the materials as well as the duration of wetting. It is therefore not possible to make conclusive observations on the impact of mechanical ageing (200 pulsations of 1000 Pa).

When the crossings of a vertical and horizontal tape are covered with a coating, the watertightness of tape A and C improves since initially most water leakages were observed at these crossings: tape A OSB: from 100 Pa to 200 Pa, tape A concrete: from 0 Pa to 250 Pa, tape C OSB: from 0 Pa to 300 Pa, tape C fibreboard: from 150 Pa to no leaks at 900 Pa. Tape C on the bituminous impregnated fibreboard therefore meets the requirement for a watertightness class 9A. The performance of tape B on OSB and fibreboard does not improve by application of a coating. This tape absorbs the coating partially and therefore influences the performance. The addition of a coating on the crossings of the silicone strip does not improve the watertightness explicitly since leakages at the joints still occur. It was observed that the effect of an extra cross of tape adhered diagonally over the crossings of tape C to the bituminous impregnated fibreboard is equal to the effect of the coating: no water leakages were observed at a pressure difference of 900 Pa and therefore the setup meets the requirements of a watertightness class 9A.

Thereafter, the complete joints are covered with a coating, which results in a large increase of the watertightness of almost all materials except for tape B on OSB and fibreboard. For tape C, no leaks were observed at a pressure difference of 900 Pa, as well as for tape A applied to concrete and the silicone strip.

Also the effect of the orientation of the tapes and silicone strip applied to OSB was tested, i.e. horizontal tape underneath vertical tape or vertical tape underneath horizontal tape. Due to the overlap of the vertical and horizontal tape, reduced adhesion can occur at the crossings, resulting in visible openings. When the horizontal tape is adhered on top of the vertical tape, these openings are oriented upwards and water can therefore directly flow through them. As a result, water leaks occurred at a lower pressure difference or after less time in comparison with a vertical tape adhered on top of a horizontal tape: tape A: 100 Pa – 0 Pa, tape B: 250 Pa – 0 Pa, tape C: 0 Pa, 11 min – 0 Pa, 3 min, silicone strip: 150 Pa – 0 Pa.

For all tapes most water leaks were observed at the crossing of a horizontal tape and vertical tape. Three types of water ingress could be differentiated, i.e. on top of the crossing, below the crossing or sideways. The first two types of water infiltration were observed for most tapes and silicone strip on the different substrates when the overlap between a horizontal and vertical tape was not executed perfectly. The third type of water ingress was mainly observed when horizontally adjacent panels were not situated in the same plane. Due to the difference in height of both edges of the panels, a reduced bonding of the tapes at these edges occurs which results in openings at both sides of the crossings through which water can flow. The watertightness of the silicone strips is mainly affected by faulty workmanship as leakages occurred where insufficient silicone is used to fill possible gaps underneath the strip and imperfections of the substrate. This was observed mainly at the crossings due to the thickness of the strips.

Conclusion

The air- and watertightness of three types of tape and a silicone strip are tested on three different substrate materials, i.e. OSB, bituminous impregnated fibreboard and concrete. Test results showed that the airtightness of the sealed joints mainly depends on the type of substrate (tape B concrete 0,005 ± 0,029 m^3/h.m; tape B fibreboard 0,051 ± 0,029 m^3/h.m). The watertightness of the tapes and the silicone strip mainly depends on the existence of crossings (tape A concrete: after ageing first leak at 0 Pa – crossings covered first leak at 450 Pa) and the adhesion of the tapes and silicone strip on the substrate. Mechanical ageing (200 pulsations of 1000 Pa) did not have a significant impact on either the airtightness or watertightness. In contrast, the first time of wetting and drying results in a better bonding of the adhesive and a reduced airflow of tape B and C mainly on the bituminous impregnated fibreboard (tape B fibreboard: before first wetting: 1,72 ± 0,36 m^3/h – after first wetting: 1,30 ± 0,20 m^3/h). Overall, faulty workmanship has an impact on the air- and watertightness, especially at the crossing of a horizontal and vertical tape or silicone strip due to the thickness of the underlying tape. Therefore, the addition of an extra cross tape adhered diagonally over these crossings is preferable to reduce the risk of openings close to the joint (tape C fibreboard initially: 0,58 ± 0,10 m^3/h and first water leak at 150 Pa – after addition of cross: 0,24 ± 0,12 m^3/h and no water leak at 900 Pa). Additional silicone can be applied at the crossings as well to reduce the air leakage of the silicone strips (initially: 1,50 ± 0,17 m^3/h - after addition of silicone: 0,29 ± 0,15 m^3/h).

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